

CRYOGENIC ENGINEERING, PRODUCTION AND USE OF INDUSTRIAL GASES

FORECAST OF DEVELOPMENT OF CRYOGENIC AND ENERGY-GENERATING INSTALLATIONS BASED ON STIRLING MACHINES UP TO THE YEAR 2010

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Patent research data on Stirling machines and energy-saving systems based on these machines are reported. Future development of directions of research for improving the key units of Stirling machines and for creating forward and reverse Stirling cycles is forecast.

In view of the huge demand for fuel and fuel-based energy resources, rising cost for their production, and growing environmental pollution, it is of high importance to search for and develop new energy-conversion technologies and techniques based on high-efficiency thermodynamic cycles and new types of fuel and working media, i.e., it is essential to create ecologically clean energy systems that meet the needs of industry and population at minimum cost of material resources [1–5].

For solving ecological and energy problems, development and wide application of energy-converting systems based on forward and reverse Stirling cycles are highly promising [6, 7]. In Stirling machines, a compressor, an expander, and heat-exchanging devices (load heat exchanger, regenerator, and refrigerator) are combined in a single unit. The working medium is generally helium, which executes in the inner loop of the machine forward or reverse thermodynamic cycle consisting of two isotherms and two isochors.

Stirling machines are distinguished by a number of virtues that provide a real ground for their wide application in many areas of industry and engineering:

- wide universality of the thermodynamic cycle that makes possible creation of forward- and reverse-cycle converters of various designs and makes;
- very high energy efficiency (theoretical efficiency of the cycle of an ideal Stirling machine and the efficiency of the Carnot's cycle are equal);
- high degree of ecological cleanness of the working media of the Stirling machines as well as of the wastes produced upon operation of the machines; and
- potential for use of local and unconventional sources of heat: solar radiation, natural gas, peat, coal, etc.

Application of Cryogenic Machines and Stirling Engines in Oil and Gas Industry. Stirling cryogenic gas machines (CGM) are extensively employed in liquefaction of technical-grade gases and in microcryogenics. Of special interest are development and creation of state-of-the-art cryogenic technologies and systems for the oil and gas industry [6–10]:

- liquefaction and storage of natural gas;
- production of liquid oxygen and nitrogen;
- recovery of light hydrocarbon fractions during storage of oil products;

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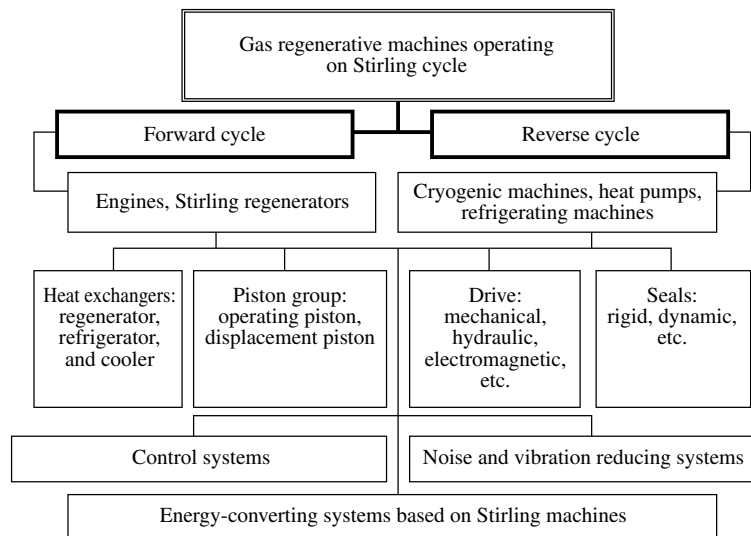


Fig. 1. Structural model of gas regenerative Stirling machines.

- long-term storage of cryogenic fuel; and
- stand-alone refrigeration supply system, etc.

Prospects of application of Stirling CGM are dependent on the high energy-efficiency of the thermodynamic Stirling cycle, ecological cleanness of the working media and processes, and significant experience of series production of these machines by the foreign and domestic industry.

Electric generators of various capacities (10–1500 kW) with Stirling engines (Stirling generators) can be used as the main, permanent, or standby source of electric power supply for overland drilling equipment and offshore oil production platforms. The fuel for Stirling engines may be natural gas, associated petroleum gas, mine methane, shaft gas, diesel oil, crude oil, fuel oil, etc.

Modern Stirling engines are fuel-efficient, have high specific indices, are reliable, meet the most stringent ecological standards, have a long operational life, are inexpensive to operate, and have the potential for operation in diverse natural and climatic conditions. The best foreign versions of Stirling engines have a specific mass of 1.2–4 kg/kW and a net efficiency of 35–45%.

Patent Research on Stirling Machines and Energy Conversion Systems Based on Them. In order to study the latest advances in Stirling machine building and to determine the major trends of development, patent research has been carried out.

In carrying out patent research, the depth (the degree of retrospection) of information search was regarded as a function of time interval for the next scientific and technical patent forecast as well as for the chosen forecasting method and the chosen characteristics of the data, on the basis of which the trend of development of the research area is determined. Considering that patent information flows into the national patent pool from some countries with a delay of 3–4 years and information on accepted applications in Japan comprising about 30% of all information on Stirling machines is published on the average after 6–7 years from the date of submission of the application, the lower limit of search time interval was in 1976 and the higher limit in 2000.

Since the subject of patent search were machines operating on forward and reverse Stirling cycles [11], which are complicated technical devices, to understand the principle of operation and component packaging and to select materials for making individual components of the machines based on analysis of the scientific and technical literature, a structural model of the machine being studied was developed (Fig. 1).

The patent information search has revealed a data file consisting of 1366 invention applications submitted by 116 companies and helped identify the countries where research on designing and building of Stirling machines is being pursued most vigorously.

TABLE 1

Country	Number of applications for subsystems						Total number of applications N_a
	Heat exchangers	Piston group	Seals	Drive	Control systems	Systems based on Stirling machines	
Russia	78	36	7	98	30	162	411
Japan	104	34	36	101	51	55	381
USA	54	31	15	86	36	48	270
Germany	46	16	3	46	11	18	140
Others	24	10	12	50	24	44	164

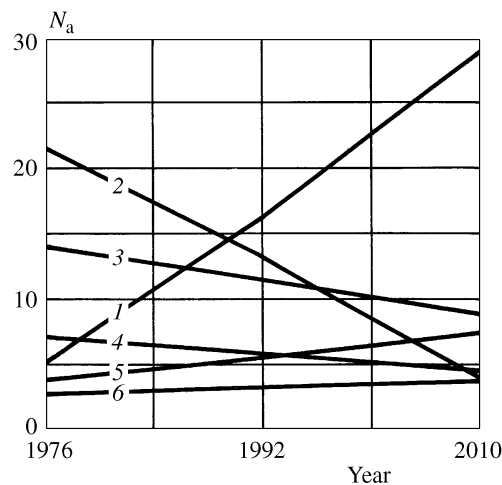


Fig. 2. Forecast of development of directions of research on refinement of key units of Stirling machines: 1) systems with Stirling machines; 2) drives; 3) heat exchangers; 4) control systems; 5) piston group; 6) seals.

The major patent-holding countries having the largest number of claims in this engineering field are listed in Table 1.

It will be seen from Table 1 that three countries lead in the number of patent documents: Russia 30%, Japan 28%, and the USA 20%. Note that the areas of research on Stirling machines differ significantly from one country to another. For instance, in Russia research is focused mainly on creation of cryogenic systems, in Germany Stirling engines and energy systems based on combined Stirling–Stirling cycle (Vieulemier–Taconis machine) are the subjects of study, and in the USA and Japan refinement of microcryogenic systems and moderate-refrigeration Stirling engines and refrigerators is the dominant direction of research.

Research and developmental work for creation of Stirling machines is also being actively pursued in the Netherlands, Sweden, England, France, South Korea, China, Israel, Italy, Poland, Australia, Slovakia, Romania, and other countries.

Of considerable interest for patent research is analysis of trends of research on refinement of Stirling machines and determination of the proportion of designs of machines operating on forward (engines) and reverse (refrigerating machines) cycles. Since 1993, the proportion of stored documents on forward- and reverse-cycle machines has been noted to be roughly equal. This trend guides the activities of leading companies, which is creation of competitive Stirling refrigerating machines, including those for moderate refrigeration. It is expected that this trend would persist over the period until 2010.

Forecast of Development of Stirling Machines until 2010. To forecast the prospects of development of Stirling machines, we used data for functional subsystems that indicate the directions of research for refinement of heat-exchanging apparatuses, piston group, seals, drive, control systems, energy-converting systems based on these machines, etc.

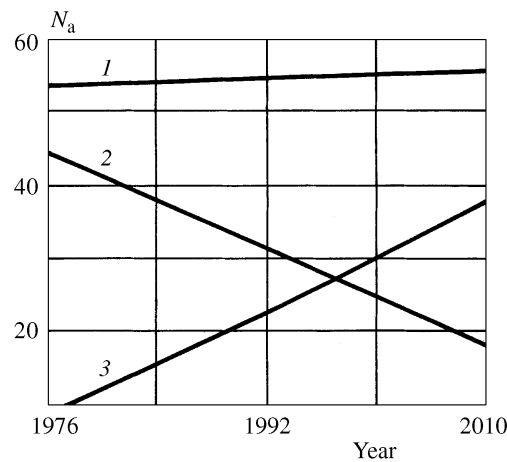


Fig. 3. Forecast of development of directions of research on creation of forward- and reverse-cycle Stirling machines: 1) Stirling machines as a whole; 2) forward cycle; 3) reverse cycle.

At the forecast research stage, we used extrapolation method and at the forecasting data analysis stage, individual expert assessment method.

To find the trends of development and promising directions of research on Stirling machines for the forecast period up to 2010, we used trend model of patent dynamics. Forecast based on time series of application submission relates to univariate forecasting methods based on extrapolation, i.e., on extension of the trends noticed in the past to the future. In this case, the course of change in the number of submitted applications N_a is related with the passage of time, which shows up in the formation of univariate time series.

Graphic representation of the obtained forecast data (Figs. 2 and 3) allows qualitative comparison of the prospects of the studied directions of refinement of Stirling machines.

The scientific and technical forecasting done for 10–15 years can be used to determine the level of engineering solutions offered today and their future potential, and to draw the following conclusions:

- forecast of the directions of Stirling machine refinement shows (Fig. 2) that there is a trend toward slowing down of growth of inventive activities on heat exchanging apparatuses, control systems, and refinement of drive. All other directions have a tendency toward rise in growth rate. At the same time, the direction for energy-converting systems based on Stirling machines has been developing most vigorously, i.e., the problems of designing of the key components have now been solved, and the developers have begun to directly build refrigerating systems for various purposes around Stirling machines;
- forecast of development of directions of research on creation of forward- and reverse-cycle Stirling machines shows (Fig. 3) that there is a tendency toward decrease in the rate of growth of inventive activities on forward-cycle machines and toward increase in inventive activities on reverse-cycle machines. An explanation for this fact is that many foreign companies began to get involved in development of high-efficiency Stirling refrigerating machines. So, in the next 3–5 years one may expect a spurt in refrigerating engineering and a dramatic expansion of the areas of use of Stirling refrigerating machines in modern refrigeration supply systems.

Inventive activities on creation of Stirling machines (forward and reverse cycles) are predicted to rise by 2010. Patent research and development of scientific and technical patent forecasting of trends of development of Stirling machines are an essential stage in building also of domestic high-efficiency Stirling machines not inferior in parameters to the best global versions.

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